Enabling Transparent Ceramics Optics with Nanostructured 3-D Materials

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We are working on a novel nano-manufacturing technique, using the electrophoretic deposition (EPD) process to create transparent ceramic optics with unique properties based on tailored nanostructures. The EPD process uses electric fields to deposit charged nanoparticles from a solution onto a substrate.

We are expanding current EPD capabilities to enable controlled deposition in 3-D by automating the injection of nanoparticle suspensions into the deposition chamber and dynamically modifying the electrode pattern on the deposition substrate. We can also use the electric field to control the orientation of nonspherical particles during deposition to orient grain structures prior to sintering.

To enable this new functionality, we are 1) synthesizing ceramic nanoparticles as our precursor material; 2) implementing new instrumentation for the benchtop deposition experiments (Fig. 1); and 3) creating modeling capabilities to predict deposition kinetics and deposited structures based on the particle, solution, and system properties.

To guide our efforts, we have identified transparent ceramic optics as a major area in which nanostructured, functionally graded materials can have a significant impact. Laser physicists and optical system engineers are currently hindered by the small subset of materials available. The only crystalline materials open to them are those that can be grown as single crystals and isotropic

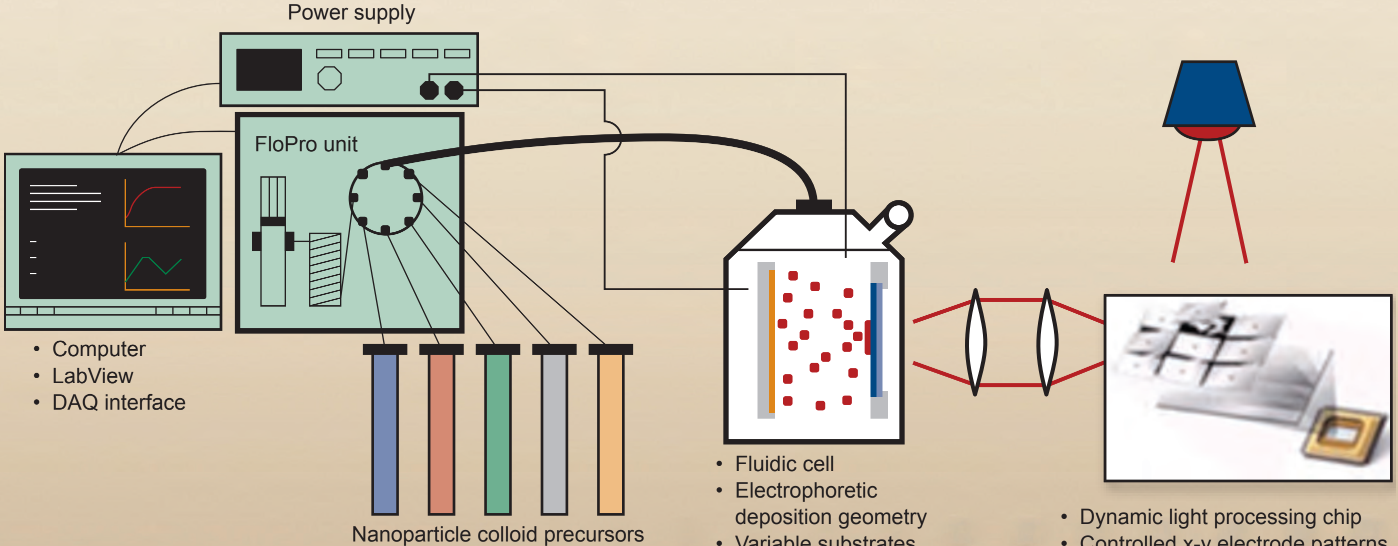

Figure 1. Schematic of electrophoretic deposition system. A FloPro unit pumps nanoparticle solutions into the deposition cell, where the computer controlled power supply provides either constant voltage or constant current between the two electrodes. A dynamic light processing (DLP) chip projects the desired deposition pattern from the computer onto one of the electrodes.

cubic materials that can be formed into transparent ceramics. By depositing nanorods of a noncubic material in the same orientation, the resulting green-body can theoretically be sintered to a transparent ceramic.

Additionally, current optics configurations are material- and process-limited to uniform composition profiles across optical components and laser gain media. To date, only coarse step function composition changes have been produced in the most advanced transparent ceramic optics. Our EPD platform will enable us to create new transparent ceramic optics with doping profiles tailored in three dimensions.

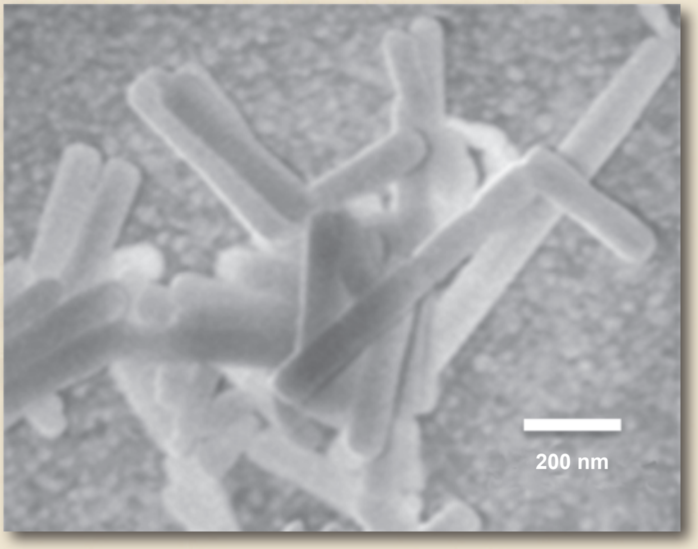

Figure 2. Fluorapatite nanowires synthesized at LLNL. The nanowires are approximately 100 nm in diameter and 500 nm in length.

Project Goals

The goals of this project are to demonstrate: 1) the fabrication of functionally graded materials with composition profiles tailored in 3-D while maintaining desired bulk properties; 2) the use of the EPD deposition field to simultaneously align nanorod particles of precursor material as they are deposited; and 3) the fabrication of composite structures with controlled material composition and create smooth or sharp material transitions along the z-axis of a composite structure.

Relevance to LLNL Mission

The project is intended to establish LLNL leadership in bottom-up nanofabrication of functionally graded materials. Our dynamic electrophoretic deposition system will position us to deliver the next generation of nano-manufacturing capabilities for projects throughout the Laboratory. Using these capabilities, we are working to produce a number of novel materials and structures. These structures will both illustrate the capabilities of the new process and demonstrate materials and structures of relevance to LLNL missions and programs. The main demonstrations for this project align with current and future needs in NIF as well as the LIFE and ALOSA thrust areas. These are: 1) to create transparent ceramic optics with doping profiles tailored in 3-D for new high-powered lasers (relevant to NIF and LIFE); and 2) to deposit aligned nanoparticles of noncubic ceramics to create a new family of transparent ceramics (relevant to NIF, LIFE, and ALOSA).

FY2009 Accomplishments and Results

Accomplishments and results in the first year include the following: 1) fabrication and testing of a new deposition chamber that enables automated injection and removal of particle suspensions and automated control of the electric field for deposition; 2) synthesis of fluorapatite and hydroxyapatite nanowires (Fig 2); 3) initiation of set-up of our dynamic electrode system with a high luminosity computer-controlled light source; and 4) integration of particle–particle interactions into the Stokesian dynamics model, which already included electrophoretic, dielectrophoretic, hydrodynamic, and Brownian motion effects.

FY2010 Proposed Work

In FY2010 we will 1) implement z-axis control and demonstrate a transparent sintered part with a depth-wise composition gradient; 2) demonstrate combined orientation and deposition control and fabricate transparent optic from noncubic material; 3) implement fixed-mask x-y control and demonstrate a transparent sintered part with a planar composition gradient; and 4) begin testing of dynamic x-y control.